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# A LABORATORY EVALUATION OF LOW-TEMPERATURE LUBRICANTS FOR AUTOMOTIVE AND DIESEL EQUIPMENT

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IMPORTANT NOTICE

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#### ABSTRACT

Satisfactory operation of automotive and diesel equipment during the Arctic winter cannot be attained without suitable lubricants. In addition to the usual requirements of lubricity, oxidation stability, and detergency, crankcase oils are required with pour points below -65°F having viscosities sufficiently low (maximum 4500 cs) to allow easy starting at temperatures down to -65°F yet capable of maintaining an adequate lubricating film (minimum 4.75 cs at 210°F) at operating temperatures.

Of the six crankcase oils tested at the Arctic Test Station, no single oil satisfied the viscometric requirements at both high and low temperatures. Bis(2-ethylhexyl) adipate, though sufficiently fluid at -65° F, was too light to prevent excessive wear in heavy-duty engines at operating temperatures. The REO-15-47 oil and Keystone 20W containing 40 percent Velo A upon the loss of the volatile diluent tended to revert to the high viscosities and pour points of the base oil and were unsuited for such applications. REO-72-49 and Ucon LB-140X give adequate lubrication at operating temperatures but require starting aids at temperatures of approximately -35°F and -25°F respectively. The pour point of the Ucon LB-140X makes it unsuitable for use where temperatures below -45°F are encountered. The RPM 5W oil will allow starts down to approximately -30°F but excessive wear is reported at operating temperatures.

No oils are available having the viscometric properties desired in a crankcase oil, therefore a compromise is required. A suitable compromise oil should have a maximum pour point of -65°F and be viscous enough at operating temperatures to prevent excessive wear. Its viscosity at subzero temperatures should be as low as possible consistent with the viscosity requirement at operating temperatures. The REO-27-49 or MIL-0-10295(Ord) oils are such a compromise. Oils with lower viscosities at subzero temperatures can be obtained if a large proportion of synthetic oils are used in their formulation.

Arctic gear oils must have maximum pour and channel points of  $-65^{\circ}$ F, and be able to support the loads developed by the gears. Additives used in their formulation should not separate in use or in storage. Seven gear oils were tested at the Arctic Test Station. Ensign 561 and Navy Symbol 9500 have too high pour points to be considered for this application, and the Ucon LB-140X and LB-400X oils fail to support the loads developed by the gears. Keystone 78-6 and Ucon LB-140X-60 are useful to approximately  $-40^{\circ}$  to  $-50^{\circ}$ F but the former showed indications of additives separation at low temperatures. The RGO-28-47 or MIL-L-10324 (Ord) gear oils performed satisfactorily in all equipment over temperatures of  $+30^{\circ}$ F to  $-50^{\circ}$ F. This oil should be satisfactory down to  $-65^{\circ}$ F since it is fluid at this temperature.

### PROVIDEM STATUS

This is a final report; the problem has been closed.

### AUTHORIZATION

NRL Problem C02-16 RDB Project NY 030-003

Manuscript submitted September 1, 1953

# A LABORATORY EVALUATION OF LOW-TEMPERATURE LUBRICANTS FOR AUTOMOTIVE AND DIESEL EQUIPMENT

#### INTRODUCTION

Conventional lubricants are not suitable for use in vehicles and engines at the temperatures encountered during the Arctic winter because of their high pour points and excessive viscosities. Since it is unlikely that military supplies can be housed in heated buildings, it is necessary that the pour point of the lubricants be as low or preferably lower than the lowest temperature likely to be encountered, generally accepted as -65°F. Unless the oil has a pour point as low as the ambient temperature it cannot be transferred from its container to the equipment in need of lubrication.

Another property desired in Arctic winter crankcase oils is that their viscosity be sufficiently low so that adequate cranking speeds for starting may be attained. Since battery efficiency decreases with decreasing temperature and ignition difficulties increase because of decreased fuel volatility and flammability, the limiting viscosity of the crankcase oil also decreases (1). However, a value of 4,500 centistokes (cs) or 20,000 Saybolt Universal Seconds (S.U.S.) is a reasonable approximation of the limiting viscosity of an automotive crankcase oil at temperatures of 0°F and below. Though less information is available for diesel engines, it is believed that the limiting crankcase oil viscosity is of the same magnitude as that for automotive engines. At temperatures below -25°F the efficiency of lead-sulfuric acid batteries decrease so rapidly that they are incapable of turning the engine at sufficient speeds to obtain starts, regardless of crankcase oil viscosity, unless the battery is warmed to temperatures above -25°F.

Two methods of obtaining low-viscosity oils are apparent. Diluents, such as gasoline, kerosene, or diesel fuel, may be used to lower the viscosity of conventional motor oils. Lower molecular weight and less viscous compounds or petroleum fractions may be used as lubricants. The lower the viscosity of the diluent, the more effective it is in lowering the viscosity of the oil (2). Pour points of motor oils containing appreciable quantities of wax are not effectively lowered by the diluents unless the wax is soluble in the diluent. As the volatility of a diluent increases with decreasing viscosity, the diluent most effective in reducing the viscosity of the oil is the least permanent and will require constant replacement. Consumption will therefore be high. The use of low-viscosity diluents such as gasoline also increases the fire hazard in vehicles.

A satisfactory Arctic winter crankcase oil must also provide adequate lubrication at operating as well as at starting temperatures. Under "short haul" and

idling conditions in very cold weather, crankcase temperatures are much below normal and cases of the lubricant congealing in the crankcase have been reported. Therefore, the viscosity of the lubricant must not be so great that it cannot be pumped to the moving parts of the engine. During long hauls and on warmer days the crankcase temperatures are essentially normal and the oil must have the lubricating ability of SAE grade 20 or 30 oils. If an oil of too low a viscosity at normal crankcase temperatures (cal75°F) is used, it will be impossible to attain normal oil pressures, and insufficient lubricant will be supplied to the moving parts. There is also the possibility that a very low viscosity oil will not have the "body" to support the loads developed in the engine. Another possible difficulty with oils of low viscosity and low molecular weight is that they may be volatilized on hot surfaces such as cylinder walls and that insufficient oil will remain for adequate lubrication.

In addition to the special properties required of an Arctic winter crankcase oil, it should also have the properties required of conventional oils. These include resistance to oxidation and to the formation of lacquer and other insoluble deposits. The oil should have the ability to prevent the accumulation of such products, commonly known as detergency. It should not be corrosive to bearing materials and should be able to protect ferrous metal parts from the rusting action of water. Neither should the oil foam badly or form stable foams.

Conventional grade transmission and differential gear oils are also unsatisfactory for Arctic winter use. Frozen transmissions and the inability to shift gears are common complaints when conventional grade lubricants are used. In an effort to prevent the congealing or freezing of the lubricant low freezing point diesel fuels have been used as diluents for gear oils. Though this expedient made the vehicles operable, the increased maintenance caused by higher leakage rates and increased wear made a better solution desirable.

Besides having adequately low pour and channel points (below -65°F), the viscosity of the gear lubricant should not exceed 22,000 cs at -65°F if excessive drag and difficulties in shifting gears are to be avoided. The gear oil should be able to support the loads developed by the gears and should not foam excessively. The additives used must be stable at the temperatures encountered and should not settle out of solution. The oil should not be corrosive to the materials it contacts and it is desirable that it prevent the rusting action of water on ferrous metal parts.

In an effort to find the most desirable lubricants for Arctic winter operation, a cooperative test program was inaugurated. The operational characteristics of a variety of experimental lubricants would be determined in Bureau of Yards and Docks equipment by the Arctic Tesi Station, Point Farrow, Alaska. Samples of oil after varying periods of use in the equipment were to be forwarded to the Naval Research Laboratory for analysis to determine the changes that had taken place during use. From the physical and chemical properties of the oils and the changes in these properties during service use, information as to their suitability for such operations and their approximate service life could be obtained. This information in conjunction with the information on operational characteristics was to be used as a guide in selecting the lubricants most suitable for Arctic winter use.

#### DISCUSSION OF RESULTS

The results of the analyses of the various experimental oils are given in Tables 1 to 11 inclusive. To facilitate discussion, the data are tabulated into groups according to the application and the oil used. These groups are further subdivided as to the vehicle or equipment in which the oil was used. Properties of the new unused oil are also shown so that the changes that took place during service may be more readily discernible. As a greater number of samples and analyses are available for study than were available in the previous reports (7) (8), it is possible to weigh the results and to draw more definite conclusions. The conclusions presented here may not therefore be the same as those based on a smaller number of observations in the previous reports.

#### Crankcase Cils

Properties of the crankcase oils are shown in Tables 1 to 4. Those of the synthetic polypropylene oxide derivative "Ucon LP-140X" are given in Table 1. This oil falls between SAE grades 5W and 10W at 0°F and is a SAE grade 20 at 210°F. It was used in the crankcases of jeeps, weasels, LVT(3)'s and a'D-6 Tractor. Ambient temperatures ranged from +24° to -47°F with -12°F being considered as the average ambient test temperature. The pour points of the used oils varied within +10°F of that of the new oil (-45°F) with but four exceptions. It is obvious from their viscometric properties that the two oils with pour points below -75°F (sample taken 9'29/48 from Jeep No. 1 and sample taken 12/18/48 from Weasel No. 2) were mislabeled or contaminated with a very light oil. The two oils with pour points of -65°F may be attributed to fuel dilution.

There was little change in the viscosities of the used oils as compared with those of the new oil at temperatures of 210° and 100°F. At -40°F, the viscosities of the used oils are approximately 50 percent greater than that of the new oil. Increases in the low temperature viscosities of the used oils are attributed in part to the solution of fuel and oil oxidation and polymerization products. Such changes in viscosities of used oils at subzero temperatures are considered about normal. No appreciable differences were noted in the viscosity characteristics of the oils used in different type engines. Evidence of the oxidation stability and extent of oxidative deterioration of oils may be obtained from the changes in their heutralization numbers. In general, the used Ucon 1.B-140X oils had neutralization number increases of 0.7 and this was attained after considerable service use. Such an increase is not unusual, and this oil is believed to have adequate stability.

Precipitation numbers are evidence of the presence of oil insoluble materials. Such products may be formed by oil or fuel oxidation or may be extraneous material such as road dust. In general, precipitation numbers increased with the length of oil use. However, the addition of "make-up" oil mashed this trend because of the diluent action of the new oil. Insufficient information is available to determine whether the increases in neutralization numbers were due primarily to oil oxidation or to the presence of extraneous materials.

The Ucon LB-140X oil appears to be in very good condition after use as a crankcase oil in the various engines, showing no evidences of excessive oxidation or other forms of deterioration. The Arctic Test Station reports (3) that wear

TALL 1 Properties of Used Crankcese 0119 Doon LB-140x

	Pate Ser le	Operation	ton:	Make Un	Esutrail-	Precipi-		7100	ority, cen	Haconity, contintoken at Op	d <sub>o</sub>		Pour
Vahiclo	Taken	Hours	Hiles	011 3ta.	sation %.	Punhor	212	150	32	0	٤,	-[a) (a)	Point, or
	:	3.	Sp 0:1		0.03	811	5.3	30-1	38	1,20	6,500	30,100	Ÿ
Joop Do. 1	9/2/1/P		022	-	0.37	0.07		u'v 2)	0,	1,0	126	1.18	<b>1-7</b>
	10/2:/1:	273	1	(9) 2	0.17	0.15	G	30.6	310	1,300	12,000	65,000	-1.5
	11/:/18	55	1.3		0.61	0.10	c.	31.0	3	1,700	10,900	9,000	Ļ
	12/11/c	165	150	,	5.31	0.25	c:-1	33.5	3	2,200	17,300	65,000	ያ
	1.04/29	10	2,36	~~	5,00	27.6	-:	35.8	3	1,970	27.51	63,000	4
	3/1.1/29	•	3	5 1/2	0	0.11.	5.7	3	3	2,000	12,800	55,000	ዩ የ
	1/11/10	•	1,115	5/13	1.13	0.35	5.6	37.3	360	5,200	υ.,ι.∞	55,000	33
	5/11/16	₹0°;	ਨ		5.50	3, 0	5	36.0	2	1,900	11,000	90,00	ş
50005	1.7.7.B	,	1,035	;	0.54	5.00	5.9	3.3	35	2,300	17.000	200,07	-L.s.
	13/11/7	:	2.073	•	0.6.7	0,0	7.5	32.3	8	1.700	16,900	1	3
	7/211/17		370	- 7	0.63	23.0	2	26.3	210	0.50	5,700	23,000	35
	1/:/18	278	2/2	1	1.76	1.03	5.6	3.0	303	1,900	000,71	35,000	-1.5
	1/13/LB	3	9.	47	0.52	0.4.5		32.8	26.	00,1	000.6		٩
	5/1:/23	251	615	Ξ	1.51	3.0	6.1	54	33	1,300	8,11	1	7
	6/1:/18	17.1	3.56	7.	3	6.3		35.6	560	1,500	000*6	000,01	45
2	a / 11/51	2	: 5	-	31.0	,	~	8	75	5	5	35 000	9
2 . Or . Osnew	2/11/10				3 -		, (		3 -	2	200	2,60	1 × 1
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	67 AT /0	52.T	/	•	1	1		0.60	r Çi	3	3	30,00	Ŗ.
P-6 Cat. Tractor	12/2017	217	•	į	0.51	0.15	4	32.6	350	2,000	17,000	65.000	-50
	2/1/2	157	;	:	0.1	90.0	5.6	57.5	350	1,100	000,6	35,000	S.
LVT(3) Ho. 1 Port Granteans	10/1/2	1.0	;	,	7770	0.17	6.0	\$5.3	2.70	6, 500	crystals	1	07-
	0,1.1.A.B	110	;*	•	7.0	0.21	()	ر اح	22	3	6.500	25,000	\$
	2/1/9	א		•	0	0.10	c.	28.9	270	1,00	2.7.3	35.000	-55
	3/10/3	ಸ	•	•	×	0.15	5.	33.4	33	1,600	10,800	2000	-1-5
Starboard Crankeaso	10/1/J.B	3	1	•	0	0.03	0.0	35.1	275	6,130	oryz talo		3
	5/1/3	ন	,		57.5	3.36	4		333	1.500	10,700	50.00	-50
	11.11	लां	;	1	0	0.13	· ·	33.3	8	1,58	0.130	7,000	-55
LVY(3) Ho. 2 Port Grankcaes	6.1/4/6	<u>:</u>	. O.		97.0	6.35	3.5	35.0	3.6	1,910	11,300	occ '95	-45
Starboard Grankcaso	14:12:3	S	2::5	٠. در تاريخ	0.61	0.15	2.5	33.1	21.	1,500	9,100	1,0,000	ያ

(a) Extrapolated value
(b) Oll changed and 2 qt. 20 H oll added

and consumption with this oil were considered normal. Because of its high pour point and high viscosity at  $-40^{\circ}\mathrm{F}$  (30,000 to 50,000 cs) this oil is not suitable for Arctic winter operations. It was somewhat more difficult to obtain engine starts when this oil was used than with lower viscosity oils. At  $-48^{\circ}\mathrm{F}$  one and one-half (1-1/2) hours of heatapplication, using a 250,000-Btu Herman-Nelson heater, were required before it was possible to crank a jeep lubricated with this oil.

Properties of the used bis(2-ethylhexyl) adipate oils used as a crankcase lubricant for jeeps, weasels, LVT(3)'s and a D-8 tractor are given in Table 2. This synthetic diester oil was obtained from two sources, that from Dupont being identified as PSP-14 and that from Ohio Apex Company as Adipol 2EH. Properties of the oils from different sources are essentially identical. This oil has a viscosity of 110 cs at 0 °F and its viscosity at 210 °F of 2.4 cs is below the minimum viscosity of 3.88 cs (39 S.U.S.) for SAE 5W oils. It was selected for tests in order to obtain information as to the lubricating ability of low-viscosity oils under Arctic winter operating conditions and also for information as to the limiting viscosity for engine starting. Because of the relatively high boiling point of this diester as compared with petroleum oils of similar viscosity.the results would not be confused by high oil consumption or wear due to the evaporation of the oil from hot cylinder walls. Ambient temperatures ranged from +30° to -50°F during tests.

It is evident that the first used-oil sample from Jeep No. 2, taken on 9/29/48, is mislabeled or contaminated. Subsequent samples tend to approach the properties of bis(2-ethylhexyl) adipate because of the addition of "make up" oil. The sample taken 1/15/49 has properties almost identical with those of the new oil except for neutralization number. Samples taken from Weasel (Test No. 2) have viscometric properties similar to those of the new oil. There is some evidence of dilution in the samples taken 5/20 and 5/31/48 since their viscosities are lower than those of the unused oil. Some of the samples from the other weasels show evidence of even greater fuel dilution. A number of samples had rather high neutralization numbers. That taken from Weasel No. 1 on 5/16/49 after 455 hours and 731 miles of operation had a neutralization number of 3.09, and its precipitation number, 0.8 was also high. Several of the samples from the LVT (3) were also contaminated with other oils as evidenced by their viscosities.

In general, the laboratory evaluation of the used bis(2-ethylhexyl) adipate oils showed that the oils from the different vehicles and engines were in approximately the same condition. The neutralization numbers of some samples reached rather high values, a possible consequence of contamination with other oils. The samples from the heavy-duty diesel engine had lower neutralization numbers than did many of the samples after comparable service in automotive engines. With the exception of the neutralization number increases, this oil showed no other evidence of deterioration in service.

The Arctic Test Station reported (3) that oil consumption was normal and that this appeared to be a good crankcase lubricant for automotive engines. Though no lubrication failures were reported crankshaft wear occurred during idling periods when oil pressure was low. This seems to be a reasonable explanation, as it is known that oil pressures decrease with decreasing viscosity and this is a very low viscosity oil. Wear on the heavy duty diesel engines was high. Automotive equipment lubricated with bis(2-ethylhexyl) adipate cranked easily down to -48°F (3,4). No starting aids or coolant heaters were necessary for starting at -30°F

TABLE 2
Properties of Used Srankosse (1)s
Ble(2-othylvsxyl) adiyate

	Date	8	Operation	3	١.	-idioa.		Y.	cosity.	Viscosity, centistokes at	kos at			Pere	
Vehicle	Teban	Hours	#176.	011	0	But er	210	8	32	0	8.	9	\$	Point, P	
			011	:	0.0	1.13	2.4	ar	3.7	110	950	950	(*) 000.9	( ab)	
(a) (c) (d)	8/100/0			:	99.0	0.12	8	8	8	1.600	10.000	000		9	
J	8/3/0	S	\ <u>{</u>	11/2	1. 16		0.0	10.	2	1.10	2	1000		Ş	
	12/6.1 8	ď	9	0 1/2	0	1,5	0		R	8	710	9	900	, ×	
3	01/21/1	? .	<b>}</b> =		7	5.17	, -	9	9	X	17.7	000	9	. <b>^</b>	
	1 1 1 1		ı						!		•				
Means (feet No. 2) (a)	5/20,14	77	\$	6 1/2	0.7	0.10	2.3	7.6	32	त्रं	280	710	2,300	<x< td=""><td></td></x<>	
	5/11,18	161	1.261	ofC	0.88	0.10	2.3	7.6	2,5	6	ž	689	2,300	K->	
(9)	4,5,78	218	1.87	:	16.0	0.12	5	9	35	8	3	619	9	\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.\.	
	0 412/0	311	a d	-	2		1 0	<b>a</b>	c		1	150	8	F	
10. 1 (a)	27/5	74.5	8.5	t u		3 0	-	o <b>a</b>	#2	25	i i	25	3 :	2 9	
9	8000	3	1.00	(4) 9	1	0.0	2	0 ~	3 2	0	3.5	2 9	000	3 K	
9	11/20,748	3.5	À	, m	1.13	0.07	2.0	7.2	₹	110	<b>(</b>	9	8	) K-	
~	57.75		য়	12	2.25	2	2.2	0	2	115	383	8	9,000	<b>1.</b>	
(e)	3/12/19	573	•		2.53	2.31	2.4	9.0	33	त्र	275	8	3.30	<b>₹-</b> *	
(c)	67,77	17.	:	7	1.71	2.57	2.1	7.0	59	8	237	8	3.00	4-7	
(0)	5/16,10	-55	731	7	3.3	3	5.0	5.5	R	73	21.	2	2,700	k. •	
(a) (a)	9/22/19	25	3	~	5.7	0.10		30.2	185	3.100	7.300	98.00		\$	
ì	13/6/51	ì	K	ľ	3	0	·	5.5	3	13	393	350	6,230	·\$-	
3	11/2/13	33	923	. 1 -	8	0.10	2.0	0.0	23	8	236	652	3,100	₹- <b>&gt;</b>	
(0)	11/22/13	93	1.078	7:12	2	S. 0	2.3	8	3	128	25.7	1,100	e, 200	473	
Managed   (4)	19723 120	3	14.	0	8	0.0	5.5	7.1		8	270	Cal.	2	K->	
i		•			!									`	
Lart(3) No. 2 Port Symmetres	(c) 11/9,28	116	:	(a)	8	0.12	2.7	1.0	3	061	3	1,930	13,000	×-7	
		£	:	1 1/2	1.35	0.10	2.3	9.	<b>6</b> 0	115	373	8	000.9	4-13	
	(c) 2/4/3	16	:	2/12	1.93	0.15	0	15.3	ĸ	26	8	00	26,000	<b>^</b> -3	
		153		•	1.20	0.17	e.	10	3	±.	3.	300	000	<-75	
Starboard Crankoase		123	:	3	<b>X</b>	0	2.7	11.6	C:	2	0	200	8	2.1	
	12/5/16	3		: .	1.13	0.10	7	-	23	3	11	3	3	<-:>	
		3 5	•	<b>→</b> •	8	2	n c	1100	C WOLD	2 2	5	1	8	ř.	
		0	•	^	2		2.0	7.0	6	2	3	3	3	21.5	
P.B. Success (4)	120/50	151	:	:	0.73	0.07	2.1	(F)	Z	1.50	1,18	1.000	6.500	ķ. • v	
(B) (B) (B)	1,5,5,1	ž	:	:	9	0	2.5	0.6	3	13.5	X	1 100	200	( P. )	
3	1/2/41	\$	:	:			010			in treneit				?	
															1
(a) Extrapoleted velue		(0)	oll designated as PSP-Li	1 PSP-L				•	Consumpt	Consumption miles/quert	/wert				
			4		7										
(b) 311 Changed		9	CII Cool Coo Long oo Wallyo! Can	. M. AG1,70.	5.7										

if the vehicles were in good condition. Ether capsules were used to start the diesel engines. At -30°F, bis(2-ethylhexyl) adipate has a viscosity of 400 cs which is so much below the limiting crankcase oil viscosity of 4,500 cs that very little battery power would be required to overcome the viscous drag of the lubricant. This oil is regarded as a border line automotive crankcase lubricant because its low viscosity makes it impossible to maintain adequate oil pressure with conventional engines. If the oil pressure could be maintained it is possible that this oil would be satisfactory for automotive engines.

Properties of the Keystone 20W (60 percent) - Velo A (40 percent) oils are shown in Table 3. This is a 20W oil containing 40 percent of a gum and sludge solvent identified as Velo A. The resulting mixture is a SAE 10W grade oil. At subzero temperatures it is non-Newtonian liquid and the viscosity values shown are therefore approximate. Pour points of the used oil samples are variable, most of them being higher than the original mixture. The viscosities of the used oils are also greater than those of the original mixture. These phenomena are a manifestation of the vaporization of the less viscous Velo A component. Samples taken on 12/10/48, 2/4/49 and 3/28/49 from the D-6 tractor show a progressive decrease in viscosities at  $-40^{\circ}$  F. It seems probable that a low viscosity "make up" oil is being added as these oils have lower viscosities than the original oil. Low neutralization and precipitation numbers indicate little oil oxidation or deterioration but this is mashed to a certain extent by the large volume of "make up" oil added. The Arctic Test Station reported that consumption rates were high due to the evaporation of the light component (3). The variabilities in the properties of the used oils caused by changes in composition with evaporation of the Velo A and the high pour points make this mixture unsuited for Arctic winter use.

Army experimental oil REO-15-47 was also used as a crankcase lubricant. This oil is a dewaxed naphthene base petroleum fraction of 8.9 cs (55 S.U.S.) viscosity at 100°F prediluted with 10 percent of a gasoline fraction. Its properties and those of the used oils are shown in Table 4. This oil has a lower viscosity than does bis(2-ethylhexyl) adipate and is therefore lighter than a SAE 5W oil. Samples received for analysis were all from a jeep. The greatest changes taking place in this oil with service were increased in viscosities and pour points due to the evaporation of the gasoline diluent. Neutralization numbers tended to approach a value of 1.0. The Arctic Test Station reported that consumption rates were excessive (3). Though the wear rates were not excessive in the jeep, concern as to the lubricating ability of this oil in heavy duty engines was expressed. Because of the high oil consumption, extra maintenance, variability in oil properties, and added flammability hazards, this oil is not considered suitable for Arctic winter use.

A new experimental oil was developed by the Army to replace the REO-15-47. This new oil identified as REO-72-49 is a petroleum oil composition containing a viscosity index improver and MIL-0-2104 type additives. It has been superseded by a similar oil covered by specification MIL-0-10295(ORD). The properties of the new REO-72-49 oil shown in Table 4 are those of a MIL-0-10295(ORD) oil as no sample of the former was received for analysis. REO-72-49 oils were used in the crankcases of a jeep, weasel and D-6 Tractor. The properties of the used oils are shown in Table 4.

Viscosities of the samples of oil taken from the jeep and that of the sample taken from the tractor in 1/20/51 are lower than those of the new oil at  $100^{0}$ F

TABLE 3 Properties of Used Crankosse Cile Reystons 20W (50 per cent)-Velo A (40 per cent)

	Date Series	Opera	tion	4				718508	ity, centi-	Tiggosity, centistokes at P	•		į
Vehicle	. sken	Houre	Miles	011-74s	P P P P P P P P P P P P P P P P P P P	Ranbe r	210	180	×	0	\$	-70(•)	Point, P
Jeep No. 2	6/11/23	82	103	2	0.00	#11 1,10	6.5	35.8 3.3.8	25	000	000,11	::	-35
D-6 Cat. Tractor	67/62/7 67/62/7 67/62/7 67/62/7 67/62/7 67/62/7	%8 <b>38</b> % <b>55</b> %%	1:::::::	29 F 2 2 2 2 2 3 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	00000 525428833	0 0 0 0 0 0 0 0 0 4 8 8 9 4 6 6 6	3.2.4.4.3.3.3 3.2.4.4.4.2.3.3.3.3.4.4.4.2.3.3.3.3.3.4.4.4.2.3.3.3.3	28.08.08.08.08.08.08.08.08.08.08.08.08.08	827.28.28.28. 827.28.28.28.28.28.28.28.28.28.28.28.28.28.	35,000	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	000°72 30°000 30°000 30°000 30°000 30°000 30°000 30°000 30°000 30°000 30°000 30°000 30°000 30°000	5 <b>2.</b> 4 8 4 5 5 4
D-5 Tractor	5005 5015/2	% हो	::	75	6.0 0.0	, o o o	5.5 5.5	10.0	14.5 516	! !	::	::	'nν

(a) Extrapolated value '

Properties of Used Grankossa Clls

	200				,	recipi-				serverity, centilatokes at I				Polat
Vehicle	Seap.io Take a	Sours and	Miles	011 0	No.	Matter	210	130	35	0	-3	07	-5(1)	do
					46.	REG - 15-47 011	011			•				
			177				2.0 (•)		28	8	230	×28	3,00	<-75
	. 100 A C.		(a) 110 mg		9 6		0.0		190	100	2,300	9,000	•	r
0.1 m	0.000/1	100	24	01/2		0 0	2.4		18	330	1,900	6,300	800	\$ .
	1 / 1 / 1 / 1 / 1 / 1 / 1 / 1 / 1 / 1 /	53			1.07		Co.		110	200	2,350	000		<b>3</b> 5
	7	510	3	1 -1	0		5		Si.	8	2	3,50		7.
	6/1/23	222	563	r pro-	0.33		2	5.11	<b>1</b> 0 5	35	8.8 -	33	38	£ 2
	5/2/5	् हो	•	Œ)	0		2.0		6	2				
					-	REO - 72-1/9 0:11	0:1							
		•		100001		-	¥. 5	3	3		2,900(1)		(*) 000,00	.x. 6
	+		1	(6/20				3 60	110		1.696		38,000	Ž,
Jeep Mo.1	12/20/50	\$ \$		112 (c)	0 0	200	2.0	0-0	101		1.357		30. 70	£
ند در این از	12/21	3 %	186	(C)	0.5	0 0	, F.	13.2	315		1 22 5 500	17,000	: :	Z.
									;			8	1	Ť
D-5 Dat. Tractor	1:/30/50	130	•	:	0	tres			2.9		3	~~~		
	1/2/1	<b>E</b> :	215	:	2		00	Solo of the	9 1	220	200	900.90	:	57-
	1/50/:1	7	9 %	:	22.0	0.03	9		( )					
					ia.	150 Mg								
					•	,		1		047	8	10,000,01		*
Jan Ho. 2	1/9/31	<b>.</b>	N= 011	23,3(c)	0.1.9	#11 0.02	- c.	8.5	32	88	36.7	17,000(=)	:	\$
	17061	: 8	ī	2 63	0	96	6.7	2	132	3	5.165	7,500(.)	:	\$
MELIE 1 10. 1 (1)	16/61/1	. 37	3		:									
Measal No. 3 (f)	1/19/51	ĸ.	8	14 (0)	6	treas	6.9	28.0	102	F.	2.74.	0,000,0	:	ŧ
2	1/5/51	9	;	;	0	0.02	5.7	21.1	LA	8	2,567	6,000(4)	:	Ł
67 -	-1 11 1	}												

(a) Extrapoletad value (b) Placometric propert

Report high oil consumption and high weer retes

Consumption miles/qt.

9 9

Piscometric properties as given in Taport on Tast of Fuels and Lubicants for Arctic Winter Operation of Astonocies Marerial 1 August 1945, Office, Chief of Ordanose

RESTRICTED SECURITY INFORMATION and 210° F. Samples from the jeep also have viscosities lower than that of the new oil at subzero temperatures. In contrast, the sample from the weasel and that from the tractor on 11/30/50 are considerably more viscous than the new oil ever the entire temperature range. Dilution is not the cause of the low viscosities as the amount of dilution in both series of samples was low and of the same magnitude. Properties of the oils differ so greatly that contamination or mislabeling was suspected until the Arctic Test Station report was received commenting on the variabilities in the properties of different batches of new oils. With the exception of the sample taken from the jeep on 1/15/51 which has a high neutralization number (2.0), there is no evidence of excessive oxidation or deterioration of these oils. It was reported (4) that this oil had good lubricating properties. Engines could be started fairly easily at ambient temperatures as low as -35°F without the use of coolant heaters or starting aids. Because of the variabilities in the properties of the new oil and the limited experience with this oil further testing is recommended with the oil in a variety of equipment.

The RPM 5W oil is a blend of approximately half and half of a synthetic polypropylene oxide derivative and petroleum oil (6). Properties of the new RPM 5W oil Table 4, are those given by Miller and Galindo (6) as no sample of the new oil was available. This oil is well below the maximum viscosity for a 5W oil, having a viscosity of 650 cs. at 0°F as compared to the 870 cs maximum for 5W oils. Its viscosity of 4.7 cs at 210°F is well above the minimum of 3.9 cs for 5W oils but is less than the minimum of 5.75 cs for MIL-0-10295 oils. It is presumed (6) that a detergent and probably other additives were incorporated in the oil.

Analysis of the used RPM 5W oils revealed that the oils from the weasels and HD-19 tractor had viscometric properties quite similar to the unused oil. The sample from the jeep was more viscous at low temperatures. All of the samples had pour points of -65° F. Neutralization numbers of the samples from the weasels were rather high, approximately 2.0 while those from the jeep and HD-19 tractor were much lower, less than 0.9. The small number of samples examined and variations in their properties makes it difficult to draw conclusions as to stability. The Arctic Test Station reported (4) that this oil tended to become very viscous at temperatures below -20° F. Viscosity determinations reveal that these oils have approximately the same viscosity at -40° F as do the M1L-0-10295(ORD) oils. In fact, they are intermediate in viscosity at this temperature to the extremes of the REO-72-49 oils. It was also reported that at operating temperatures (140° to 180° F) the oil lost body and the engine lost power. No lubrication failures have been reported.

#### Gear Oils

Properties of the gear oils are shown in Tables 5 to 11 inclusive. Table 5 lists the properties of the synthetic Ucon 1.B-400X oil used in the differential, transmissions, final drives, and transfer cases of jeeps, weasels, D-6 tractor and the Little Giant Tractor saw. The used oils changed little in properties from those of the new oil, only the sample from the differential of the tractor saw had a high neutralization number. Though the oils change little in physical or chemical properties with service several of the samples contained metal particles. Analysis of the metals present in the sample taken 2/3/48 from differential of the jeep revealed the presence of large amounts of copper, lead, and tin in addition to iron and nickel. It is evident that besides the abrasion of the steel gears the copper alloy bushings or bearings were badly worn. The same metallic

Froperties of Used Geer Offia-Doco 15-LOM

Public   P				3 2	Operation	1100	Mahamin		Precipi-		Via	:0117, 0	Viscosity, centistokes at Op	40 30 I		1004
Profit Efficiential   Profit Efficiential		Vehiole	Application	Taben	Bours	Hiles	011-9te.	sation No.	Baber	213	8	32	0	-35(*)	Q.	Point, ?
Differential   1/27/4					2	<b>:</b>		<b>%</b> 1	111	1.1	95.6	300	5,660	000.04		-35
Front Differential   1/77/4	Jeep		Differentia:		4	X.T	1	, ii.	0.10	0.7	23.4	8	1,100	5,700	27,000 (4)	1
Front Differential 177/28 345 511 0.04, 112.0 75.6 800 1,596 35.000 512 0.04 112.0 75.6 800 1,596 35.000 512 0.04 112.0			Front Elfferential	1,27/1.8	ii i	350	1	0.1.	5.0			775	\$	38,000	1	35
Bast Differential   1777/43   1777			Front. Differential	2/3/18	1	:	1	0.1.	0.0	13.3	7	8	8	35,000		-35
Parameter   2/3/4			Roar Differential	5.7.3		S		5.11	0.0	1:.0	4	8	1.506	8		-35
Transition 2/3/4 74 5.00			Beer Differential	2/3/3	•	<b>:</b>		2.30	3.0	11:5	3	200	186	300		-35
Transfer Case 1/27/LB 259 0.11 0.04, 11:0 76:0 5:635 12:000 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			Trenemission	2/3/18	1	F.	1	3.00	0.0	1		35	250	2.83		ę,
Transfer See   2/3/48   1.2/23/47   1.2/			Transfer Case	1/27/18	, j	52		0.11	20.0	0	78.0	8	5.061	3,000		3
Interfer Case			Transfer Case	2/3/18	1	2	10		Lrace	=	8	8	5.633	2,80	1	-35
Differential (Test #1) 12/23/47 373 3.12 3.13 1.14 81.6 81.0 950 6,183 65,000 5.15 11.0 81.0 950 6,183 65,000 5.15 11.0 81.0 950 6,183 65,000 5.15 11.0 81.0 950 6,183 65,000 5.15 11.0 81.0 8			Transfer Case		1	7,15	•	0.83	0.12	7.4	67.0	3	6,811	8.00		÷.
Differential 1/77/Le - 3.073	Iseas.		Differential (feet [1])	12/23/27	1	ĝ	•	50	0::0	15.00	5.16	1.300	2,772	20,000		-35
Differential 1/31/48 64 5.19 0.05, 1L.6 0.1, 1,500 5,021 L5,000 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			Differential	1/27/Le	1	3.023		5.0	0.50	9	0,08	8	6.189	8		-35
Transmission 6/27/7 560 (5) 0.11 0.21 11.0 60.6 1,100 6,604 52,000 170 0.03 11.1 56.0 980 6,077 18,000 170 0.03 11.1 56.0 980 6,077 18,000 170 0.03 12.7 78.2 900 5,941 13,000 170 0.04 13.7 65.6 980 6,070 18,000 170 0.04 13.7 65.6 980 6,070 18,000 170 0.04 13.7 65.6 16,000 12,000 12,000 12,11 13,7 975 6,116 5,000 12,000 12,11 13,7 975 6,116 5,000 12,116 13,11			Differential	1/31/48	ić E	3		5,19	0.0	÷.4	9).1	200	5,021	1,5,000		4.5
Transmission 12/79/L7 370 0.00 14.1 56.0 980 6.077 18,000 170 0.17 0.00 12,7 78.2 900 5,941 13,000 170 0.11 0.00 12,7 78.2 900 5,941 13,000 0.11 0.00 13,7 78.6 900 6,070 18,000 0.12 0.13 0.10 13,7 75.6 16,000 1 0.13 0.14 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15			Transmission:	42/11	Ü	\$6 (5)	10	1.0°	0.21	٥. بر	8.0	1.100	6,804	2,000	1	የ
Transmission 1/10/LB 1/19 0.17 0.00 12.7 78.2 900 5,941 LJ,000 17 0.04 13.7 95.6 960 6,070 LJ,000 17 0.04 13.7 95.6 960 6,070 LJ,000 17 0.04 13.7 95.6 960 6,070 LJ,000 17 0.05 13.7 97.6 96.0 LJ,000 17 0.05 13.7 97.5 97.5 97.5 97.5 97.5 97.5 97.5 97			Transfesion	22/20/27	Ti.	25	1.1	8.0	0.08	-1	0.36	86	6.077	000	1	\$
Transmission 1/10/LB 15 0.11 0.04 13.7 65.6 960 5,070 18,000 1 0.04 13.7 65.6 960 5,070 18,000 1 0.05 15.0 0.05 13.7 65.6 10,000 1 0.05 15.0 0.05 15.1			Translasioo		1	617	1	0.17	0.00	12.7	78.2	8	5.841	000	1	#\ #\
Transmission and 2/7/.8 344 0.15 transmission and Differential Co. 12.9 13.2 13.2 13.5 15.66 10,000 12.51 15.1 15.1 15.1 15.1 15.1 15.1 15.			Transmis a ton	1/10/18	1	<u>.</u>	16 16 16	0.11	0.04	13.7	8,	\$	6,070	000,841		-35
Differential 2/7/18 354 0.15 true 13.2 675 5,666 10,000 13.2 675 5,666 10,000 13.2 675 5,666 10,000 13.2 675 5,000 13.2 675 5,000 13.2 675 6,000 5,00	De Cat.	Treetor	Transmission and													
Final Drive 12/1/1/17 217 3.25 3.00 15.1 31.7 975 5,1146 55,000 Laft-Final Drive 2/3/13 554 3.21 0.04 13.2 93.2 900 6,262 55,000 Right-Final brive 2/3/18 554 3.21 0.04 13.7 64.3 1,000 7,210 66,000 Transmission 2/16/13 (5, 2.09, 0.75 161 31.2 340 2,591 25,000			Differential	2/7/3	35	i		3.16	traca	87	93.2	675	5.666	000	1	-35
Loft-Final Drive 2/3/LB 354 3.21 0.04 13.2 83.2 900 6,262 55,000 Right-Final Drive 2/3/LB 354 3.21 0.04 13.7 84.5 1,000 7,210 60,000 7 2 2/16/LB 54 2.09 0.75 181 312 340 2,581 25,000			Pinel Orive	12//27	213	1		0.53	20.0	12.1	91.7	570	0.446	80.0		13.
Right Final Drive 2/9/18 354 =			Loft-Fitcal Drive	2/3/1.3	746	1	1	12.0	0.0	11.2	80.2	8	6.262	55.00	1	-35
Transmiss 100 2/16/48 45 47 4 5.00 0.75 1.41 31.2 340 2,501 25.000			Right Pinal Orive	279/1.8	×	j.		0.21	0.0	15.7	 6	300,1	7.210	0000	1	<u>۹</u>
	Little Gi	len t	Transmiss 100	2/16/20	\$	)4: 31	•	2.00	£.	1.41	31.2	OF.	2,581	×.000	1	2
		(														

(a) Extrapolated value (b) Second Draining

constituents were found in the sample from the differential and transmission of a weasel. The presence of these metals, in such large amounts, confirms the report of the Arctic Test Station that abnormally high wear rates were observed in the differentials and transmissions of equipment lubricated with the oil. Evidently the Ucon LB-400X does not have sufficient "load carrying capacity" to support the heavy loads developed by the gears and it is not recommended as a gear lubricant.

Properties of the Ucon LB-140X a lower viscosity grade oil than the 400X are shown in Table 7. There is evidence of the admixture of other oils in the sample from LVT(3) No. 2 taken on 2/4/49 as it consisted of two liquid phases. The higher viscosity Ucon oils are not completely miscible with petroleum oils. Though there is some variability in the properties of the used oils, possibly due to contamination with other oils, the used Ucon LB-140X oils were not badly oxidized while in service. There was visual evidence of metal particles in several samples of the used oils and this was confirmed by the report (3) of excessive wear in vehicles using the oil as the gear lubricant. High wear rates would be expected as the 140X grade has the same composition, though it is less viscous, than the Ucon LB-400X oil. It is not recommended as a gear lubricant.

The Ucon LB-140X-60 oil differs from the Ucon LB-140X in that the former contains an extreme pressure additive. This oil falls in the SAE 75 grade as a transmission oil, see Table 6. It was used in the differentials and transmissions of a jeep and weasels and in the transmission and final drive of a D-6 tractor. Samples taken during the winter of 1949-50 have somewhat lower viscosities than those in the winter of 1950-51. This is believed due to difference in production batches rather than to changes caused by service use.

No appreciable changes in physical or chemical properties occured during service and the oils appeared to be in good condition. There was no evidence of unusal wear in the samples submitted for analysis. The Arctic Test Station reported (3) excessive wear of jeep and weasel transmissions lubricated with this oil and later (4) reported satisfactory operation in jeeps, weasels, and tractors it is suspected that the high wear rates first reported were due to the use of the Ucon LB-140X which does not contain an extreme-pressure agent. Though this oil gave satisfactory performance at the lowest temperature encountered, -50°F, difficulties in shifting gears and excessive drag would become more apparent at lower temperatures. Because of its high pour point (-50°F) and viscosity, this oil is not suitable for use at temperatures down to -65°F.

Properties of the Ensign 561 gear lubricant are shown in Table 7. This oil does not conform to the new SAE requirements for transmission oils. It is less viscous than a grade 90 oil but it cannot qualify as a grade 80 oil as its pour point is above 0°F. Though no major changes in the properties of the oil due to service use were observed its high pour point, above 0°F, makes it unsuitable for Arctic winter use.

Navy Symbol 9500 oil is a heavy-duty crankcase oil, SAE grade 50. As a transmission oil it would be classified as SAE grade 90. The properties of the new oil shown in Table 7 are those of a typical oil conforming to the specification and are not necessarily those of the new oil used in these tests. There is a drop in the viscosity of the oil with service use. Oils from the final drive had lower viscosities than did those of comparable service in the transmission. However,

TABLE 6 Properties of Used Gear Cila Ucom 1.8 14/38-50

		3	00444400	100			Precipi		Viscosi	ty, cant	Viscosity, cantietokes at	•		Posite
Vehicle	Appliestion	Taken	Boure	M1 la.	011-26	sation No.	Man ber	210	381	8	0	-25	-10(•)	Point, OF
			F 011	011			111	5.9	33.2	Ê	1.73	12,820	00,00	8
Jeep No. 2	Front Differentia:	6/1/9	300	127	1	0.1.0	0.05	6.6	32.7	0.1	2,300	12,800	3,00	-55
	Sear Olfferentie.	0 1.13	9	Pi-	:	0.83	90.0	0.5	32 €	510	1,900	11,300	000,04	-55
	rensminsion	61.173	200	121	:	0.10	0.13	5.0	32.1	OF T	S	13,100	20,030	ያ <sub>-</sub>
(Page 1)	Differential	5/27/39	200	7777	2	5.7.3	0.00	6.3	32.2	310	1,800	11,900	000,001	Ŗ
	•	SV. 13	1	070	na	0.65	0.07	5.1	33.5	3	2,000	12,500	7,000	ş
Lease 1 to 1.	•	2/2/5	(2)	8	(4) 662	0.59	0 0	5.5	8	362	1,550	98	55,000	£5.
Mennel No. 2	Transaleston	L'Asolis	128	633		35.0	8.0	0.5	32.1	310	1,900	200	000,0	F
	•	0/22/5	101	193	:	0	0.0	0.5	33.1	O X	2,300	13,200	50,000	-55
	•	らいている	33	į	27.	0.33	50.0	5.1	33.5	9	2,000	13,000	000 9	Ŗ
Sec. 2 (7-8)	•	175610		583	•	0.50	0.10	5.1	33.0	O'X	000	13,000	000	ş
Monsel No. L.	•	12/11/50	ž	3	(4) 0	3.0	0.02	\$	9,	275	1,600	12,000	60°,000	57-
D-6 Cat Tractor	Transmission	31/2/20	र्छ	:			* between	into two						
	•	1./23/50	8		:		separated 1	into two						
	•	12/18/50	177		:	7.0	LIBOR	5.7	32.7	<b>36</b>	200	13,000	36,38	Ϋ́.
	•	1/2/51	*	1	•	0 0	trass	2.1	32.5	2002	3	13,000	86,58	-1.5
	•	1,48/51	32	•	:	0.1.6	LFROG	5.3	32.7	3	1,700	3	65.00	<b>9</b> .
	•	1/52/2	212	•	:	0.3	traca	2.1	33.0	310	1.78	13,500	98	-45
	•	2/12/51	8%	•	:	· 3	Lrace	5.9	33.5	3	2	12,500	86.58	የ
	Pinel Drive	11/13/50	. ਤੰ	:	(4) 0	0.1.2	trace.	2.5	32.2	8	3,650	12,000	55,000	8
	•	05/62/11	8	:	(4) 0	0.51	F. B.O.	5.4	31.6	8	200	12,500	00 ज	5
	•	12/19/50	201	,	(4) 0	0.1.3	60.00	5.9	35.1	R	3	3	23,000	-15
	•	1/2/21	21.5	:	:	510	Lraca	5.7	31.0	565	3	13,000	000,79	8
	•	1/13/51	27.7	:	:	0.36	LIBOR	5	32.2	2	170	12,500	000 17	577
	•	1/25/51	3.52	:	:	0.0	LIBOR	5.1	32.5	2	32	12,500	63,000	£5
	•	2/12 41	577	:	:	0.30	-F.00	E 5	52.9	S	22	12,500	000 (s)	7

(a) Extrapolated valua (b) Consumption miles/quart

TABLE 7 Properties of Used Gear Oils

		Date		1			Precipi-		Viscosit	y, centi	Viscosity, centistokes at op	0		90000
		Seple	100111111111111111111111111111111111111	1100	Kake-up	Meutrali-	Lation Manber	210	81	2	0	ķ	97	Point,
Vehiola	Application	in the second	BOOL											
						Tool 18-11,0X								
				-		0.0	11	5.7	30	8	1.20	9,500	% 100 ·	-45
Dec Cat. Irector	Transmission	7/20/13	5	:	:	95.0	90.0	9	21.5	195	0.00	2,690	25,000	3
	Pinal Drive	7/20/LR	507	ì	:	0.27	50.0	3.7	2.1	O'R	1,100	9,790	1,5,000	Ş.
LVT(3) No. 1	Port Iranmissico	10/3/08	9		:	0.69	20.0	5.	37.1	3	5,000	13,900	000'0	ş
	Starboard Transmission	3,	9	•	:	0.8	0	9	57.5	त्र	1,400	7,100	900°	8
			75	•	:	6.0	0.13	3.	33.9	3	8 2	12,700	000	-55
	•	2/1/18	57	•	:	0.71	0.23		8	3	1,00	9,100	000.00	8
	•	3/3/10	ž	•	-3	0.57	g.	0	0	8	8	9,910	31,000	ţ.
177(3) 80. 2	Port Transmission	555	43		H \ P	8 - 6 6	0.0	.;	9	-	8	:	:	ş
	Starboard :ranges;ssion	5/1/2	6	:	٢		3	5			0.00	•		
						Pro 100 CA1								
						3								
			Now Old	111		3	3	11.8	112.6	2,100	:	•	:	۶
Rease! No. 1	Transmission	9/21/10	115	99	1/2	1.58	0.0	5.6	105.6	2 21.0	9000	•	:	-15
	•	10/6/10		711	1 1/1.	1.11	0.03	9.1	113.1	2,530	000	:	:	-15
	•	81/61/c1	•	1.865	1 1/2	2	0.03	7.	102.2	986.	16,000	•		-15
	•	11/20/13	\$	8	1 1/2	8	0.03	.:	80.3	1.50	13,000	•	•	-15
	•	12/27/10	776	1.273	: 1/2	1.54	0.03	9.1	113.9	250	3 80 3 8	:	•	÷1-
	•	5,12/19	:	24.	:	1.55	0.0	5.7	109.9	2.1.2	3000	•	:	-15
	•	3/22/2	:	34.5		1.79	0.0	0.6	111.7	200	37,000	:	:	
	•	2//	•	1		G. 1	0.0	5.0	112.0	33.	000	•	•	-15
	•	5/15/2	3	F;	:	1.13	0.0	0.6	117.2	3.1%	80.0	:	:	-15
					×	May Syabol 95x0								
			,	(4)		0.3/ 1	M 1	18.5	235.0	5.000	:	:	•	·15(max)
Tall Transform	000000000000000000000000000000000000000	1/21/51	, g	3	:			11.7	12.5	200	29,300	:	:	-15
		2/10/51	101		:	0.10	N1.1	17.0	202	8	000 00	:		-15
	Finel Series	1/25/51	3	:	:	0.57	0.0	1	1	2 100	000	:	:	-15
	•	2/10/51	ेंट्र	10,	,	0.22	0.05	13.6	150.8	2 500	25,000	:	:	-15

(a) Extrapolated value (b) Approximate properties of Many Symbol 9540 old the relatively high pour point,  $-15^{0}$  F, of used oils, and the specification requirement of  $+15^{0}$  F maximum pour point would eliminate this oil from consideration as an Arctic gear oil.

Properties of the RGO-28-47 gear oils are shown in Tables 8 and 9. This oil is now covered by specification MIL-1-10324(ORD). They are less viscous than the lightest oil covered by the SAE transmission classification, grade 75. Table 8 lists the properties of the oils used in differentials, transmissions, and transfer cases of jeeps: Table 9 gives the properties of oils used in the differentials, transmissions, and final drives of weasels and a D-8 tractor. Pecause of the non-Newtonian nature of these oils at low temperatures, the viscosities shown at subzero temperatures are approximate.

Properties of the used oils from the jeep are extremely variable. A number of samples have much higher viscosities and pour points than the new oil. It is possible that some increase in pour point and viscosity could be attributed to oil deterioration during use but the changes are so great that contamination with more viscous oils is suspected in a miscority of instances. Additional evidence of contamination is that the changes in properties are not regular, i.e. there is no orderly increase or decrease in viscosity or pour point with use. For example, the samples from the differential of Jeep No. 1 after zero, 142, 231, 394, 590, and 881 miles of operation have the following viscosities in centistokes at 100°F: 12.3, 13.8, 17.6, 16.2, 13.8, and 15.0. At -40°F, their viscosities are: 2,400, 5,000, 10,000, 13,000, 6,000 and 6,500. Their pour points show a similar variability. Oils taken from the transmission of this jeep after comparable mileages show changes similar to those for the differential oils. Other used oil samples have properties closely approximating those of the new oil, as exemplified by samples from: front differential of Jeep No. 2 on 1/9/51, rear differential of Jeen No. 2 on 1/2/51, transmission of jeep (new) on 3/3/48, and transmission of Jeep No. 1 on 9/29/48. All of these samples had low precipitation numbers but there is some variability in their neutralization numbers. It is possible that difference in the neutralization numbers of different procurement batches of oil may be responsible for part of the variability observed.

Other samples of oil show very great changes in properties after comparable service, e.g. the sample taken from the front differential of the jeep on 6/7/48 after 165 miles of operation had a viscosity of 30.9 cs at  $100^{0}\mathrm{F}$  and 15,000 cs at  $0.^{0}\mathrm{F}$ . Its pour point was  $-30^{0}\mathrm{F}$ . Six out of the 37 samples of used RGO-28-47 oils had pour points above  $-40^{0}\mathrm{F}$ . It is suspected that the used oil samples with physical properties greatly different from those of the new oil were caused by contamination or admixture with other oils. All of the used oils had low precipitation numbers and the neutralization numbers were relatively constant at about 0.8 to 0.9, evidence that the oil was reasonably stable and that the additive content had not changed appreciably.

Samples of RGO-28-47 from the weasels and D-8 tractor. Table 9, are not as variable in properties as those from the jeep, Table 8. The exceptions are samples taken in the winter of 1951 from the final drives of the D-8 tractor. These samples have viscosities of 21.6 to 43.2 cs at 100°F as compared to 12.5 cs for the new oil. Evidently they contain varying proportions of a more viscous oil. In general, the used oil samples from these vehicles do not differ greatly in viscosities and pour points from those of the original unused oil irrespective of their use, i.e. differential, transmission or, final-drive gear oils. None of the

Properties of Usad Sear Olls RGG-28-17

Particular   Par	1 1		Semple	3		The The	atton	100	1					4	1-137	
Column   C	- 101					0.1-0	Member	100	017	100	35	0	ç.	Ì	33.0	1
Differential   10/71/16   11	-	pplication	: aken	Bour		2										
Description   19/2/16	-											9	8	6	20 800	\$
Column   C	-			0	(4) (1)		1.5 max	1111	3.0		8	2;	3	2	CF 000	K
Continue	-		8 / W/C		C'.		0.0	0	0	d.	8	2	2	3	2000	1
Differential   1974   1975	Δ 13 1	Allerentin.	2/23/20		120		8	20.0	3.0	17.6	9	8	8	30.0	:	3 5
Differential   Virgin   Virg	ω,	M ferential	01/1/01		3		- 0	0		6.11	153	\$	S 80.0	8	:	8
Differential   Milks	•	Lfferential	12/5/48	•	大		0.00	6	1		8	CAN	1,930	90.0	00°	だし
Fig. 2   Differential   Sylicida   Sylicid		he Characters	1/4/19	•	8	•	0	7	2		2 0	3.	2 040	200	000	K.
Continue		100000000000000000000000000000000000000	VIV	•	993	:	2.00	8	3.5	0	707	000	3 8			
Front Differential		יוו וביים ביים	10000		2		0	0.00	-	22.5	111	200	3	22.00	1	1
	2	Mifferential	16.26	171	X.		8	C	7	2.5	Š	8	•	•	•	
		Tront Differentia:	5/15/1B		1,000			2		0	900	35,000	•	:		05-
March   Marc	•		5/1/nB	:	E.		5	0.00		?:	۶	2	1,600	2.00	8	٩
Column   C		•	3/17/19	•	961		2	0.63	6.3		3 5	, #	90	900	65.000	-75
			11.110	;	1,115		8.0	0.0	2.	1	10	-	8			q.
			60.04	10.	7		0.75	0.07	5	9.6	1	9	3.6	5	21 000	**
				} "	3		0.13	0.00	5.5	6.01	Z	27	3	2000		2
Mar Differential   War	¥0. ≥		1,1	2	900		0	0.0		21.7	2	2,100	3	•	,	32.
Transferior (Jaw 1) 1970 1970 1970 1970 1970 1970 1970 1970		Wer Differential	7		27		93	80.0	3.2	¥,	3	8	•			. 5
1			0/1/		5		2 4	8	-	16.8	120	5,20	2,70	8	•	Ş
Transition (New)   1/2	1 10. 0		7.7.9	<b>2</b>	127		000		4	10 6	æ	9	9	2	8	2->
Transmission (Few)   1/2/51   15   25   25   25   25   25   25			6717		1,115		5	5 6			110	O.L.	1.320	2,00	•	8
Transmission (Fer)   1/2/51   33   237   11   11   11   11   11   11   11			:		ম		0	6.0	0.0		4	216	8	2.700	23,50	\$\$\circ\$
Transitation (New ) 2/1/4 - 170			1/2/5		232	•	0.15	5	100	1	83		9	2 300	22,000	£.
		(year) colon (lea)	3/1/18		270	:	5/	0.10			3 2	200	000	11.000	:	ş
		00,00,00	6/1/2		30,	-	8	0	•	0.0	F	28.2	1,716	200	32,000	V-12
			0/20/18		11,2	:	3.0	0.0	5 · 0	7.00	1	010	. 2	8	•	ş
11,4/18 yo			A 10/0		231	:	0.8	0.0	1	0.0	2	2 .		3	000.00	2
1,5   1,0		•	a VV		123	1/2	1.00	0.09	7	16.8	9	3	2010			*
7.5%   7.			07/2/10	2	2	, ,	1.07	0.0	3.4	17.1	125	9	2	3	8	2.5
7.7.7.6 - 31			2/0/10				90.0	0.15	3.1	:i	8	415	8.	3	300	. F
7.17/19 341			6.7%		1	•		000	1	16.8	110	8	2,070	82.0	32.00	2 8
1,11,5		•	3/11/18		100	•		,	0	0 11	8	095	902	8.	8	2
\$\langle \begin{array}{cccccccccccccccccccccccccccccccccccc		•	13/19		1,115		3			0.0	20	×	1.370	900	35.000	<u>.</u>
9/89/46 121 52 - 0.93 0.07 1.1.6 90 1/30 2/165 9,000  1/4/51 38 2/6 0.42 treat 2.5 11.16 90 1/30 2/165 9,000  1/4/51 38 2/6 0.42 treat 2.5 11.16 90 1/30 11.00 11.00  1/4/51 3 2/6 1.10 11.00 1.10 11.00  1/4/51 1/5		•	671179		r.		0	11.0	2.6		196	4	000	11,000	•	F
7/4/31 58 256 0.12 trace 2.5 11.5 11.00 11.00 0.12 trace 2.5 11.5 11.00 11.00 0.13 11.00 11.0		•	9/20/6		X		0.93	0.07	;	3:	5.8	2.5	2 1.51	000	•	4
1 Transfer Set 5 1 1026 None 5.36 5.00 5.1 15.1 72 15.5 5.00 5.00 5.00 5.00 5.00 5.00 5.00		•	1/5/1	_	256		0	LTBOR	5.5	0.5	2	2.5	36		:	-35
1/2/13 30 11.30 1.30 1.30 1.30 1.30 1.30 1.3			S. J.S. A. B.		:.028		0.08	0.0	1	6	510		3	8	:	<u> </u>
3/23/19 131 112 - 0.75 0.05 3.7 27.5 3.0 1.100 - 1.100	-		6/1/8		165		0.77	0	3	5.5	7	60	3		•	9
1/5/18 590 551 1/4 0.17 0.05 5.9 21.1 175 590 10.00			a Vary		0.7		0.75	50.0	er,	23	O i	200	?-		,	ş
11/2/14 334 231 331 342 15.9 35 15.9 35 15.9 35 15.0 25.00 2			10/1		1 2		0.77	50.0	6.1	21.1	165	2	1		8	ř
737/8 121 52 - 1.50 0.31 5.6 19.1, 11.7 650 5.160 10.000			11/2/1		2.5		.00	00.00	3.0	15.9	6	566	1,870	2.500	3	, T
2/20/16 12: 52			13/29		113		. 8	5	•	10	11.7	36	2.	10,00	•	7
	Las 16. 2		3/30/18		X		5		•							

Typical vistmetric properties at given in "Report on Test of Puels and Lubricants for Arctic Minter Operation of Agreenties Material" - August, 1877, Cffice, Thief of Ordnance (a) Extrapolated value

3

Operation of Used Seer Oils

			Operation	1100						. 621 to	reconity, occiletokes of				Pour
Vehiole	Application	Taken	Houre	11100	311-76	a square	3	210	8	Ω	٥	ķ	ch-	(•×6-	Poist, or
			i	(4) (8		1.5 mx.	=	3.0	12.3	Ł	230	8	2,1,00	20,000	£.
	Differential	5/25/3	2	615		8	40.0	3.0	12.9	Z	3	1,000	2,800	25,000	£
		1,11,0	:	C.		0.6	0.0	5.3	-		35	950	2.60	2,000	8
Though No. 1		1/17/16		200		(=)	(e)	3.8	4.7	250	0	36.0	•	•	<u>.</u>
	•	19/74	J	P.		0.36	· Land	2.7	9.01	÷	ス	36	2,,00	000,0	<b>4</b> +65
1 10. 3	•	13/0	36	563			0.15	2.5	11.5	*	250	1,115	3,000	00,00	\$
	The passes of the	2/12/18	:	3		0.0	· July	3.2	17.2	0.1	90			•	-35
•	•	1.14/19	•	3		3	0.00	0.	13.0	9	100	•	,	•	÷
	•	5/15/le	381	615		ਰ <u>ਂ</u>	100		10.1	27	3	Q.L	2,130	16,300	ş
		2/14/10		F7		1.12	10.0	6	:1.1	×	000	8	1,930	•	ş
10. 1	•	26/21	8	×		0.3:	Lynce	1.3	0	1.0	98	667°	8	67,000	\$
	è	03/31/	u	5		0.35	· Lrace	3.1	15.2	91	3	1,2,1	1,500	200,00	*
ì	•	1.5/31	2	5.6	5,501.1)	, de	40 EL 3	2.5	::	, i		30	000	25,350	<b>.</b>
Deft Tractor	Control Legion	11/11/50	ý	•	•	- 1	*****	0		11.	0,1		000,71	:	\$
	•	02/00/	8	;		0	LFBCB	0	11.7	R	3	1.00	5.30	8.3	\$
		17/11/50		•	•		trece	60.0	.:	¥.	2	120	200	000	\$
	٠	7			•	5.0	0.03	 		K)	Q.	1.25	83.	36,000	\$
	٠	1,10/61			;	0.00	L'esc.		5	ይ	93.7	1,123	001	000,3	\$
	•	1,77,1		1	:	0.0	trace	6	10.9		350	1,132	3.	3,3	\$
	•	10.6		2	•	3.0	-12.	6	*	£	Ź	23.	2	20.2	£
	•	27.5.16.			:	0	STBC.	5.7		ń	340	1,1	2,130	35,000	<b>*</b>
	Pipel Spines	3/31/11		•	•	-	Lraos	٠.	2	5	;:	100	11,000	•	9
		11/2/6				0.0	35.	٠.	11	22.	3	3000	5,733	1	×
	•	1,15,50	40	•			Lreos	3.3	17.6	×			3	000,01	\$7°
		1		2	•	.:000	bottle b	Centra	in trea						
		1/12/5:			•	3.3	2.01	0.5			1,	1, 16.2	32	80.	4
	•	1, 1/6,1		•		2.66	2.15	3.5		í	:	A	3	•	Ť
	•	1	2			67.0	0.07	5.0		1.4.	r	04:	3	•	7

(a) Extrapolated value
 (b) Typical viscometric/properties as given in "Mayort in Thermoof Finals and Lutricus for Arritic Minham Operation of Automotive Material" - 1 August 1847, Office, Chisto of Ordanose
 (a) Insulficials a sample
 (b) Consemption, miles/just

RESTRICTED SECURITY INFORMATION

samples had appreciable precipitation numbers but there is a greater variation in neutralization numbers. Samples taken during the winter of 1948-49 had neutralization number of approximately 0.9 while those from the winter of 1950-51 had a value of approximately 0.5. This is attributed to differences in the original neutralization numbers of the different lots. Possibly a lesser amount or a different extreme-pressure additive was used in the preparation of the oils.

Though the used RGO-28-47 oils show great variations in properties, this is attributed to the admixture of other oils rather than to oil deterioration. A sufficient number of the used oil samples have properties so similar to those of the new oil that it is believed justifiable to conclude that the RGO-28-47 or MIL-L-10324(ORD) gear oils show no evidence of excessive deterioration during use in the various vehicles and applications. The Arctic Test Station reports satisfactory operation with this oil (3, 4), gears shifted easily, and there was no evidence of sluggish vehicle operation down to -50°F. No indications of excessive wear were observed.

Properties of the Keystone 78-6 Hypoid gear oil are shown in Tables 10 and 11. This oil has a viscosity of 817 cs at 0°F as compared to the maximum of 3,268 cs for a SAE grade 75 gear oil. It is considerably more viscous than the RGO-28-47 oil (817 cs as compared to 230 cs) and has a higher pour point. Table 10 gives the properties of the oil after use in differentials, transmissions, and transfer cases of jeeps and weasels. Viscosities of the oils taken from Jeep No. 2 are so much lower than that of the new oil that it is suspected that it has been contaminated with another oil, probably RGO-28-47. Pour points of the oils. except those that are obviously mislabeled or contaminated, vary from -45° to -60°F. The lowering of the pour points of the used oils may be a result of a better dispersion of the additive due to the shearing action of the gears. The Arctic Test Station reports (3) that some material settles out of this oil on standing. It is probable that the upper oil layer would have a lower pour point than the lower layer. Therefore, the lower pour points of the used samples could be due to the precipitation of the additive in the original container or while in the vehicles. The viscosities of the majority of the oils had changed very little. Precipitation numbers were generally around 0.1, which is not excessive, and neutralization numbers varied from 0.4 to 1.0. These variations may be a manifestation of the precipitation of the extreme pressure agent.

Properties of the gear oils used in LVT(3)'s, D-6 and D-8 tractors are given in Table 11. A number of samples in this series are evidently mislabled or contaminated since their viscosities at 100°F are much greater than that of the new oil. Several had viscosities of 73 cs at 100°F as compared to 20.7 cs for the new oil. Other samples had viscosities intermediate to these values. Samples with the high viscosities also had much higher pour points, up to -5°F. In general, the pour points of the used oils were approximately the same as that of the new oil, -45°F. A few samples had lower pour points, possibly due to the better dispersion of the additive or to its precipitation. About half of the used oils had properties similar to those of the new oil and showed little evidence of oxidation or deterioration.

Except for the precipitation of additives, the Arctic Test Station reports that this gear oil gave satisfactory performance in all vehicles and equipment down to temperatures of -50 °F. No excessive wear was observed; gears could be shifted easily; and there was no appreciable drag on the vehicles. As this lubricant has

indum 13 Properties of Used Gear Oil: Espatone Hypoid 70-5

		Dese	Operation	100	Make up	Neutrali-	Precipi-		71.0061	Hecosity, contistoins		30		
Vehicle	Applitation	19690	Bours	Miles	91 - 84	Masher	TE LOT	210	3	25	Э	-33	(*)(*)	Point, P
				011			tracs	7	70.7	31	917	000	000,00	3,7
5	Differential	12/6/13		8		1.06	, K. 0	6.3	5	8	3	1.90	5,100	2.
		1/15/10	:	54%		1.15	0.05	5.5	10.0	51	2	1,920	8	5
	COLUMN SECURAL	13/2/3		007		6.0	70.0	3.0	01	365	54,0	1.50	005	<b>₹</b>
	•	1/15/19	:		:	1.02	20.0	2	1 2	ĸ	80	23	000.9	<b>^-</b> ₹
	Transfer Case	12/5/18	•	3		3.0	0.0	0.7	12.0	£9	360	8	005.7	<b>&lt;-7</b> 5
														;
Keass1	Differential	8/1/2	:	980	State		0.20	5	1	3.	120	13,00		Ç.,
	•	5/5/3		8	Note		0.0	10	B. 30	S.	0	17.000	•	Ç
Fearel Mo. 1		21/13	115	G)		1.86	0.15		85.35	3.	1.00	0.500	17,000	9
	•	10/1/2		-1		0.17	0.13	O	10.10	88	1,130	0,000	27,000	3
	•	10/13/13	:	3.50	(±)	1.03	0.11	0	R	195	050	5.330	23,000	<b>3</b>
	•	1/20/18	2	i		5.	10.0	7	19.6	8	301	7.20	000,00	7
		12/27/18	1-	3,	•	0.0	60.0		26.7	8,	1.150	0.00	35,300	3
	•	2/2/3		7	:	0	0.15	40	8.5	50.	000	S.0.3	22,000	<b>3</b>
	•	1/1/2	•	2	1 1/2	0.58	0	0.7	19.1	3	2.6	5,000	18.00	÷
	•	5/16/19	365	356	•	0.1.0	20.0		27.	210	900	5,58	18,000	9.
Tease No. 2		8/63/6	54	172		90.0	0.07	4	0.1	<b>_</b>	ंग	2.70	300	<b>6-1</b> 2
		10/2/1B	;	12		5.97	0.10	-1	21.	3	0.00	0.370	000,22	9
	•	172/38	•	3	:	0.75	60.0		8	Q	0.00	5,100	22,000	9
		11/25/18	:	933		0.0	0.09	d' H'	23.1.	9.~	250	9,000	000	32
	•	12/11/2B		111		0.55	10.0	**	8.5	178	86	200	•	9
Mease, Mo. 5	•	12/8/50	S: :3	122		0.97	0.03	- 2	16.5	127	3	8	2000	\$
	•	2/1/51	전	N	724,(4)	0.13	0.05	er n	21.1	178	008	5,000	19,000	ş
We hat a	Fransmission	5/25/18	•	1.099	None	3.1	2.0		16.1	3.	755	3	15,000	\$7
	•	5/5/mg	•		50	1.38	0	0.0	12.5	95	3	2 300	9	£.
Messel No. 2	•	9/30/6	X)	25.6	•	1.05	0.15		5.5	96.	1,100	7,510	32,000	ş
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(a) Extrapoleted velue
(b) Sample conteminated with "Arciic Winter Antifreste"
(c) Oll changed
(c) E. C. B. C. - Port Center Bearing Take Off
8. C. B. T. C. - Starboard Center Bearing Teke Off

a pour point of -45°F, difficulties with gear shifting, stiff axles and channeling would be expected at lower temperatures. This oil appears to be marginal as an Arctic winter gear oil.

### SUMMARY AND CONCLUSIONS

The two crankcase oils containing volatile diluents, REO-15-47 and the Keystone 20W (60 percent) - Velo A (40 percent) show great variations in properties due to the evaporation of the diluent. The extra maintenance required because of the high oil consumption; the increase in low temperature viscosities and pour points make these oils unsuited for Arctic winter use. The synthetic Ucon LB-140X though giving satisfactory performance and lubrication at operating temperatures and startability at temperatures down to -20°F becomes so viscous at temperatures below -30°F that starting engines becomes difficult. Its pour point of -45°F is also too high for satisfactory winter serivce where even lower temperatures may be encountered.

Bis (2-ethylhexyl)adipate oils, identified as PSP-14 and Adipol 2EH, are apparently on the border line of viscosity at operating temperatures for automotive engines. It seems probable that the oil pressure cannot be maintained at a level high enough to assure adequate lubrication. In heavy duty diesel engines, wear is much greater. Though this oil allows easier starting at subzero temperatures, its viscosity is too low at operating temperatures for the satisfactory lubrication of heavy-duty engines.

The used REO-72-49 or MIL-0-10295(ORD) oils were extremely variable in properties ranging from 4.0 to 7.3 cs at 210°F and from 3,300 to 26,000 cs at -40°F. Differences in dilution were not great enough to account for these variations (3, 4). The Arctic Test Station reports considerable differences in the properties of the new REO-72-49 oils which probably accounts for the variations observed in the used oils. This oil is considered the most suitable Arctic winter crankcase oil by the Arctic Test Station as engines could be started fairly easily at ambient temperatures as low as -35°F without the use of coolant heaters or starting aids. Consumption rates were rormal and less wear was observed in the heavy duty diesel engines using this oil. Some used oils had pour points as high as -45° and -50°F which is above the maximum of -65°F. It is possible that these high pour points were due to contamination with other oils.

Properties of the used RPM-5W oils were fairly consistent, all having pour points of -65°F. Two of the samples had high neutralization numbers but there was no major change in physical properties. Because only four samples were available, two of which had much lower neutralization numbers, no conclusions can be made as to their oxidation stability. Low temperature viscosities of the oils do not bear out the Arctic Test Station report that this oil becomes very viscous at temperatures below -20°F. The viscosity of the oils examined at -40°F were intermediate between the extremes of the REO-72-49 oils. Viscosities at 100° and 210°F revealed no unusal drop in viscosity as reported by the Arctic Test Station. Oil consumption was said to be high and adequate lubrication was not attained in diesel engines.

Three unusal requirements are asked of Arctic winter crankcase oils.

I. They should have the lowest possible viscosity at subzero temperatures to

facilitate starting with the least number of starting aids. Viscosities at -40°F and lower temperatures are desired that are comparable to those of a conventional oil at 0°F. II. Viscosities must be sufficiently high at operating temperatures which approximate normal operating temperatures, to maintain an adequate oil pressure and oil film to prevent excessive wear. Ill. The oil must have a boiling point high enough so that consumption will not be excessively high and so that it will not volatilize from hot cylinder walls leaving an inadequate oil film. No known oil, petroleum or synthetic, fills the requirements for such a crankcase oil. Therefore, a compromise must be made with some sacrifice at either operating or at starting temperatures.

REO-72-49, a petroleum base oil containing a viscosity index improver and MIL-0-2104 type additives, is a compromise oil. Some sacrifice in the low-temperature viscosities were made to obtain higher viscosities at operating temperatures. MIL-0-10295(ORD) oils have similar properties but this specification allows latitude as to composition in that oil may be petroleum or synthetic or a combination of the two. The RPM 5W oil is also a compromise, having a lower viscosity at operating temperatures than the REO-72-49 or MIL-0-10295(ORD) type oils but approximately the same low temperature viscosity characteristics. A crankcase oil having the viscosity of that of a MIL-0-10295 oil at 210°F but with lower viscosities at subzero temperatures could be prepared by using a larger amount of synthetic oil or a wholly synthetic oil. This would increase the cost, but if operational characteristics were improved sufficiently it would be warranted.

The Ucon LB-140X and Ucon LB-400X oils were unsatisfactory as gear oils because of their inability to support the heavy load developed by the gears. Excessive gear wear and failure were reported when these oils were used as gear lubricants. Navy Symbol 9500 oil and Ensign 561 are not suitable as Arctic winter gear oils because of their high viscosities and pour points. The former, a heavy-duty crankcase oil, probably would be unsuitable as a gear lubricant because of its inability to support the loads developed.

Ucon LB-140X-60 differs from Ucon LB-140X oils in that the former contains an extreme pressure agent. This oil showed no evidence of excessive oxidation or deterioration during service. Its operational characteristics were satisfactory down to -50°F, the lowest temperature encountered. Wear rates were normal and no lubrication failures were reported. Satisfactory operation with the Keystone 78-6Hypoid gear lubricant was also attained down to -50°F with no evidence of excessive wear or lubrication failures. The decrease in pour points of the used oils could be attributed to the precipitation of the additive or to their better dispersion in service due to the shearing action of the gears. Though there was little evidence of oxidation instability or deterioration in the used oils the tendency of a component, probably the extreme pressure additive, to separate during storage could lead to trouble. Wear rates would increase as the concentration of the extreme pressure additive decreased. Both the Ucon LB-140X-60 and Keystone 78-6 gear oils have pour points of -450 to -500F. At lower temperatures, excessive drag and difficulty in shifting gears would be expected. The channeling of the gears through the lubricant leaving them unlubricated also becomes probable. These gear oils are considered marginal for Arctic winter use because their pour points of -45°F are above -65°F, the lowest temperature expected.

The conclusions based on the results of the analyses of the used RGO-28-47 or MIL-L-10324(ORD) gear oils are obscured by mislabeled or contaminated samples. However, from the number of samples showing little changes in properties during service it appears that this oil is adequately stable. The Arctic Test Station reports that it has given satisfactory service in jeeps, weasels, and tractors at temperatures from  $+30^{\circ}$  to  $-50^{\circ}$ F. Consumption was low and wear rates normal. Because of its low viscosities at subzero temperatures and pour point of below  $-65^{\circ}$ F, it appears to be the most suitable gear lubricant for Arctic winter use evaluated to date.

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RESTRICTED  SECURITY INFORMATION  LUNCICARIA  LUNCICARIA  A LABORATORY EXAMATION OF CON-INFERATURE LUBRICARTS FOR AUTOMOTIVE AND  Test results  2) pp., Morebar 17, 1933  2. Dissel engloss  Arcite inter cannot be sitained eithout suitable luncicants. In addition  Arcite regions  3. Internal combustion  Arcite regions  3. Internal combustion  Arcite regions  4. Internal combustion  Arcite regions  4. Internal combustion  Arcite regions  4. Internal combustion  Arcite regions  5. Internal combustion  Arcite regions  6. Internal combustion  Arcite regions  7. Cohen, G. Land Arcite regions  8. Cohen, G. Land Arcite regions  9. Internal combustion  Arcite regions  10. Cohen, G. Land Arcite regions  11. Cohen, G. Land Arcite regions  12. Litylhavyli adjaste, though sufficiently fluid at -69°F, sas too light  12. Litylhavyli adjaste, though sufficiently fluid at -69°F, sas too light  12. Litylhavyli and Arcite regions of control of the passe oil and everal to evert to the high visconities and litt.  11. Nonderson, C. W. Pour points of the base oil and ereca unsulted for such applications.	RESTRICTED  SECURITY IMPORTATION  Naval Research Leboratory. Report 19239  Lubricants —  A LABORATORY EVALUATION OF LOW-IMPRICANTS FOR AUTOMITY AND  Test results  2 pp., Movember 17, 1993  C. Lamb, C. M. Monderson, and C. M. Worphy  Setisfactory operation of automotive and disast equipment during the 2-  Arctic state cannot be stained without suiteble lubricants. In addition  to the using requirements of Lubricity, ovidation stability, and deter-  Arctic regions  1 internal combustion  to the using file (and all why) or teal all and pour points below -6.9° f having  y viscosities sufficiently for teal allow and stability, and deter-  calling file (and all why) or an allow temperatures. Of the  Arctic regions  1 cohen, G.  1 cohen, G.  The ROAL STAINES of Properation and of seat supparatures. Of the  Laboratory of Prevent oversalve sear in heavy-dury endines at operation temperatures.  1 Laboratory of the Viscosities requirements at both high and low temperatures. Of the  Laboratory of Prevent oversalve sear in heavy-dury endines at operation temperatures.  1 Laboratory of the Viscosities requirements at both high and special of temperatures.  1 Laboratory of the Viscosities requirements at both high and special of temperatures.  1 Laboratory of the Viscosities requirements at both high and special of temperatures.  1 Laboratory of the Viscosities requirements at both high and special of temperatures.  1 Laboratory of the Viscosities requirements at both high and special of temperatures.  1 Laboratory of the Viscosities requirements at both high and special of temperatures.  1 Laboratory of the Viscosities requirements at both high and special of the Viscosities of the Viscosi	RESTRICTED  RESTRICTED  SECURITY IMPORTATION  Naval Research Leboratory. Report 4739.  Test results  2 pp., Moreber 17, 1933  2 biesel engines —  Lubricetion —  Arciic vieter cannot be stained eithout suitable lubricants. In addition  Arciic regions  1 internal combustion  Arciic regions  3 internal combustion  temperatures does to 400 ff at a complete points below -690 ff having  Arciic regions  Arciic mine in addition  to the usual requirements of lubricity, ordering at addition  to the usual requirements of lubricity, ordering at 3.  Arciic regions  Arciic regions  Arciic mine in an arciic fine and an arciic feat Stailon, no single oil satistic feations.  Arciic regions  1 conexces oils tasted at the Arciic feat Stailon, no single oil satistic feation.  I cohen, 6.  12-ethylhavyli adjate, though sufficiently field at edger; see too light	RESTRICTED  SECURITY IMPORATION  Lubricants
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reported at operating temperetures. No oils ere evallable having the viscometric proparties desired in met seperate in use or in storage. Seven gear oils mere tested at the Arctic Test Station. Ensign 361 stacoalty et subzero temperetures should be as fow as possible, consistent eith the viscoalty requirewith lower slacosities at subzero temperatures can be obtained if a large proportion of synthetic oils a crantices oil; therafore e compromise is raquired. A switzbie compromise oil should heve a maximum temperatures but require starting elds at temperatures of approximately -350F and -250F respectively. ment at operating tamparetures. The REG-27-49 or MIL-0-10295fördi oits are such a compromise. Dits sepacation at ion temperatures. The REG-28-47 or MIL-L-1042410-di geer oils performed natisfactorily and be able to support the loads developed by the gears. Additives used in their formulation should ere used in their formulation. Arctic geer oils must have maximum pour end chennel points of -690F, power point of -650 F and be viscous anough at operating temperatures to prevent excessive sear. Its and devy Lymbal 9500 have too high pour points to be considered for this application, and the Ucan 18-19-84-59 are useful to approalmetely -400 to -500F but the lormer showed indications of additive (B-1908 and (8-400% oils fall to support the iseds developed by the gears. Keystone 78-6 and Ucon The pour point of the Ucon LE-140X makes it unsuitable for use where temperatures below -450F ars in ail equipment over temperatures +30°F to -50°F. This oil shiwid be satisfectory down to -69°F encountered. The RPM 9% oil mill allow atanta down to approximetely -30 PF but escessive sear is lince it is fluid or this temperatura.

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esported at operating temperatures. No oils are available having the viscometric properties desired in met separate in use or in storage. Seven gear olls ware tasted at the Arctic lest Station. Insign 362 elacacity at subzero temperaturas should be as loc as possible, consistent elth the viscosity requirewith lower eleconities at aubzero temperatures can be obtained if a large proportion of synthetic oils temperatures but require storting elds at temperatures of approximately  $-39^{0}{\rm F}$  and  $-25^{0}{\rm F}$  respectively. a grankense oli; therefors a compromise is required. A suitable nompromise oli should have a maximum deparetion at low temperatures. The MGD-28-47 or Mil-L-1032410rd! gaer oils performed setlafectorily ment at operating temperatures. The REG-27-49 or Mil-G-1029510rds olis are such a compromise. Olis and mad in their formisation. Arctic pear oils mest bare maxima pour and channel points of -690 F. and be able to support the toads developed by the gears. Additives used in their formulation should powr point of -650 and be viscous enough at operating temperatures to prevent excessive east. Ita EBARGOL-EQ ere weeful to epproximately -400 to -500F but the forest showed indications of edditive and thang spanes 9900 have too high pour points to be considered for this application, and the Ucon LE-190X and LB-400x oils feil to support the loads developed by this geers. Aeystone 18-6 and Ucon the pour point of the Ucon 18-146X makes it unsuitable for use whire temperatures below -490F are by eif equipment over temperatures 4300k to -500k. This oil should be satisfactory down to -650 hoencountered. The RPM 54 oil elil allow sterts down to approximately -36 but excessive seer is since it is fluid at this temperature.

# SECURITY INFORMATION

reported at operating temperatures. Mo oils are evaliable having the viscometric proparties dasired in not asparete in use or in storage. Sevan gast oils were tested et the Arctic Test Station. Ensign 961 viscosity at subzero temperatures should be as los as possible, consistent eith the viscosity requireeith fower viscositiss at subzero tamperatures can be obtained if a lerge proportion of synthetic oils a crankcase oil; therefora a compremise is required. A suitable compremise oil should here a maximum separation at low temperatures. The RGO-28-47 or MIL-L-1032w10rd1 gest oils performed satiafectorily temperatures but raquire starting aids at temperatures of epproximately -39°F and -29°F respectively. ment at operating temperatures. The REG-21-49 or MIL-0-1029516rd1 oils are such a compromise. Olis era used in their icraulation. Arctic gear oils must have maximum pour and channel polats of  $-69^{0}\mathrm{F}_{\mathrm{y}}$ and be able to support the loads developed by the gears. Additives used in their formulation should pour point of -65°F and be viscous anough at operating temperatures to prevent excassive ever. Its and Mavy Symbol 9500 mave too high pour points to be considered for this appilection, and the Bcom LB-140X and Lb-400X oils fall to support the loads daveloped by the geera. Keystone 78-5 and boom 18-140x-60 are useful to approplantely -400 to -500F but the former showed indications of additive the pour point of the Ucon 18-140% makes it unsuitable for use where temperatures below -450F are In all equipment over temperatures  $\pm30^9 \mathrm{F}$  to  $\pm90^9 \mathrm{F}$ . This oil should be setlefactory doen to  $\pm65^9 \mathrm{F}$ ancountered. The RPM 5M oil elil elilos starts down to approximately -30 PF but excessive mear is since it is fluid at this temperature.

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reported at operating texperatures. Me offix are exaliable having the viscometric properties desired in not seperate in use or in storags. Sevan geer pila sery tested at the arctic fest Station. Entign 562 vicensity at subsest temperatures should be as ion as possible, consistent with the vincosity requireeith lomer vitcosities at tubbaru temperatures can be obtained if a lerge proportion of synthetic oile a crankcase oil; therefore a comprehite is required. A suitable compromise oil should have a maximum heperation at low tamperatures. The MGO-28-w) or MIL-k-10%20.0rd) goer dits parformed setlafactorily ment at operableg temperatures. The REG-21-49 or MIL-C-10295tord offs are such a compromise. Offs tamperaturas but raquire starting oids at temperatures of apprissimately - 39 F and -25 P respectively. are used in their formalation. Arctic year olia must have maximum power and chemnel points of  $\omega \xi 9^{0} \varepsilon_{y}$ and be able to support the loss's developed by the geers. edditives used in their formulation should pair point of -600° and be alatout enough at operating temperatures to proutal exceptive seath. Its end any symbol 9900 have the high pour points to be considered for this application, and the Scon lb.lyof and (8-your ults tall to support the foads developed by the geers. Payatone 74-6 and Ucon 18-1401-60 ere usaful to appropriessals, was to -50°F but the former showed indications of additive The pour point of the Ucon (0-2-0) nakes it unswiteble for use where temperatures below -150k are in all equipment ovar temperaturas explor to -yeop. This oil should be satisfectory down to -oglor encountersd. The RPM of oil will after starts down to approximately -30°F but excessive sear it lines it is field at this temperature.